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Singularity functions as new tool for integrated project management

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Abstract

Construction managers plan and control quantitative measures for successful projects. Current techniques for time, budget, and resources are compartmentalized, but should be integrated into a cohesive model. The methodology adapts singularity functions from structural engineering. They activate a dependent variable over a range of an independent variable. Yet their analytical capability had ignored interfaces between measures. Pairwise interactions link quantitative elements and enable a customizable approach that facilitates multi-objective optimization. This research contributes in that models of time, cost, and resources are aligned; interactions are formalized via the common variable time; and the possibility of higher order models is discussed.

Keywords: Cash flows; integrated project management; quantitative performance measures; scheduling; singularity functions

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1. Introduction

Construction project management is a complex system, as it is driven by multiple objectives; “[t]hese objectives and their relative importance vary from one project to another, and they often include minimizing construction time and cost while maximizing safety, quality, and sustainability” [1, p. 17]. The term ‘objective’ can also be used interchangeably to the term dimension, as traditional project management is commonly defined as a three-dimensional (3D) cost-schedule-technical system [2]. To handle the characteristics of such a complex system, previous studies divided construction projects into various subsystems. They typically focused on one compartmentalized subsystem as their research purpose, while simplifying or even omitting interfaces to other subsystems. For example, Gantt bar charts are a graphical scheduling method that is oriented exclusively toward the time dimension, ignoring others such as work quantity, cost, and resources. The well-known Critical Path Method (CPM) was developed for the re-

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quirement that “[t]he plan should point directly to the difficult and significant activities – the problems of achieving the objective” [3, p. 160]. CPM may be described as a one-and-a-half dimensional method, because it primarily applies an algorithm to schedule time, while a separate later time-cost tradeoff analysis could consider direct cost, but not indirect cost [3]. More recently, additional dimensions (often three) are brought into multi-objective models. They were solved “using a variety of methods, including linear programming, integer programming, dynamic programming, and genetic algorithms” [4, p. 477]. But CPM still dominates as their limiting foundation to the detriment of other dimensions. Yet construction projects are integrated systems that unfold in a complex interplay subject to a plethora of factors, which requires using a more integrated model to generate realistic analyses and efficient optimization. A need exists to explore novel approaches toward such an integrated systems view of project management.

2. Literature Review

Traditional research “selected [the] most important objective while either neglecting the less important competing objectives or imposing them as known constraints in the optimization formulation” [5, p. 1411]. Such studies on single objectives usually explore a detailed *subsystem*, e.g. scheduling [6] or cash flows [7]. But construction projects are complex systems and thus it is deplorable that there exists “a plethora of “control” techniques that cannot provide any insight into the interactions among the many components of a construction engineering project” [8, p. 494]. To manage multi-objective problems, studies seek to create “tools and strategies that can simultaneously improve project performance in multiple dimensions” for *integrated systems* [9, p. 30]. Yet “[m]ultiobjective optimization formulations have clear theoretical advantages but increase the complexity of the mathematical formulation” [5, p. 1411]. In most cases, researchers make approximations to simplify problems. Ammar [10, p. 67] for a time-cost tradeoff optimization explained that a “[d]iscount factor in the exponential form…, is too complicated to be handled in a mathematical optimization model… Instead, a simplified form… will be used.” Such approach is common in multi-objective research for simplicity, manageability, and brevity of a model and its description, but undesirable.

Furthermore, such studies typically follow very similar steps: First, selecting objectives from project performance parameters to be minimized or maximized, e.g. time, cost, or resources. Second, using a multi-objective optimization algorithm. However, an important intermediate step is often short-changed, that of creating a model whose nature is ideally suited to its challenge. It logically occurs between establishing the objectives and performing an optimization and is crucial for an efficient and reliable optimization. Models must be *versatile* yet *accurate* to the maximum extent that input data allow, without imposing extraneous restrictions from modeling assumptions. Prior studies have focused extensively on optimization algorithms [11], but appear to overlook this modeling challenge.

2.1. Research Need and Objectives

Abridged objective functions to minimize or maximize dependent variables radically simplify reality: Duration is determined by factors such as productivity, crew size, resource availability, shifts, lead/lag durations, buffers, etc.; multi-objective studies omit most such details. Cash flows must consider direct and indirect cost, bill-to-pay delay, prompt payment discount, credit limit, interest, time value of money, etc. Objective functions typically simplify these details, focusing instead on algorithms to identify or compare solutions. One may argue that it is overly complicated to maintain the same level of detail as local *subsystems* when moving to modeling a global *integrated system*. But per Ockham’s razor, whose paradigm advocated ‘as simple as possible, as complicated as necessary’ for models, one should not reduce realism if a system becomes more complex, which limits the validity of its output and may mislead decision-makers. This research raises the fundamental question of how to bridge local and global views, while remaining efficient and accurate as determined by the quality of available data, not model assumptions. **Singularity functions**, defined in the following, offer the unique features of *detailability* (can reflect any desired level of detail within their mathematical expressions), *extensibility* (can incorporate any number of interacting dimensional variables), and *convertibility* (can extract pairwise performance parameters to examine their relationship).

Three sequential **Research Objectives** will be addressed by this research, which together contribute to its overall goal of ultimately gaining a single comprehensive yet customizable approach to construction project management: